HANDBOOK

for

Power Supply Unit

MODEL TCU - 150

A·P·T ELECTRONIC INDUSTRIES LIMITED

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Designers and Manufacturers of Specialised Electronic Apparatus

H A N D B O O K

for

POWER SUPPLY UNIT MODEL TCU-150

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SECTION 1

SPECIFICATIONS

General

1. Power supply unit Model TCU-150 is a general-purpose wide-range transistorized power supply for laboratory and test room use and is one of a family of similar units of various current ratings. The family consists of the following members.

TCU-0550	0-50 Volts	0.5 Amp maximum.
TCU- 150	0-50 Volts	1.0 Amp maximum.
TCU- 250	0-50 Volts	2.0 Amps maximum.
TCU- 550	0-50 Volts	5.0 Amps maximum.
TCU-1050	0-50 Volts	10 Amps maximum.
TCU-2050	0-50 Volts	20 Amps maximum.

All these units are similarly styled and are based on similar performance specifications. A special feature of these units is their small size in relation to their ratings.

2. Model TCU-150 provides an output of up to 1.0 Ampere at any voltage in the range 0-50 Volts. The output voltage range is covered in five decade steps, with continuous variation of voltage over each decade. Neither pole of the supply is earthed internally and the supply may be operated at up to 500 Volts d.c. with respect to earth.

3. The central feature of the front panel is a 4 inch rectangular moving coil meter with two scales, covering 0-50 Volts and 0-1 Ampere. An associated meter switch permits either output voltage or output current to be measured.

4. An overload protection system is incorporated, combining an instantaneous current-limiting action with a delayed trip-out action. The sensitivity of the overload protection system can be varied by means of a six-position switch on the front panel. Resetting of the system after an overload is by means of a push-button placed centrally on the front panel.

Mains supply

5. The standard model TCU-150 is designed for operation from 200-250 Volts single-phase a.c. at 50-60 c/s nominal. Voltage selector screws at the rear of the unit permit the transformer tappings to be set to the actual nominal voltage of the supply mains.

6. An alternative model, TCU-150/A, is available which is identical in all respects except that it is for operation from a 100-125 Volts a.c. mains supply.

7. The power supply unit is designed to tolerate supply voltage variations of up to ±10% around the nominal voltage for which the transformer tappings are set, and is rated to maintain its full performance over this range of voltage variation.

8. Models TCU-150 and TCU-150/A are designed for mains supply frequencies in the range 48-62 c/s and are not frequency sensitive within this range.

Output voltage

9. The output voltage is controlled by the five-position range switch and the continuously variable fine control, both on the front panel. The range switch changes the output voltage in 10 Volt steps and the fine control covers a total range of just over 10 Volts, to ensure that there is no gap in the voltage coverage over the range 0-50 Volts.

Stabilization ratio

10. The stabilization ratio tends to vary with the output voltage setting but is typically of the order 3000:1. All units are tested to ensure that the performance is not worse than the following.

From 5-50 Volts,	stabilization ratio not less than 1500:1
From 0-5 Volts,	stabilization ratio falls to not worse than 1000:1 at the lower voltages.

Output impedance

11. D.C. Resistance. The mean value, measured as change in output voltage for a load current change from zero to 1.0 Amp, is not greater than 0.002 Ω.

12. H.F. Impedance. Measured under small-signal conditions the h.f. impedance rises to a flat maximum at around 60-100 kc/s. Over the range from zero frequency to 1 Mc/s the impedance is less than 0.3 Ω.

Ambient temperature range

13. The power supply unit is rated to deliver full output current, i.e. 1.0 Ampere, at ambient temperatures up to 40°C maximum.

14. There is no lower temperature limit at present specified for this unit but the design is intended for general-purpose laboratory and test room use and it is assumed that ambient temperatures below 0°C will be unlikely. It is possible that in low ambient temperatures, around 0-5°C, there may be a slight deterioration of transient response and h.f. impedance characteristics during the first few minutes of operation, until the power unit warms itself slightly. This effect is due to the deterioration of certain of the characteristics of electrolytic capacitors at lower temperatures.

Temperature coefficient

15. The variation of output voltage with ambient temperature is not entirely linear but to a close approximation it can be expressed as a temperature coefficient. Over the range 10-40°C the effective temperature coefficient of voltage is not worse than 0.02% (200 ppm) per °C.

Dimensions and weight

Height	10.1/2 inches	(27 cms)	
Width	5.1/2 inches	(14 cms)	
Back depth	7.1/2 inches	(19 cms)	over terminals and all projections.
Weight	13 lb 8 oz	(7.33 kg)	

SECTION 2

OPERATING NOTES

Mains voltage selector

1. The mains voltage selector is at the rear of the unit and consists of two insulated selector screws which have to be inserted in the appropriate positions.

2. The two screws should be inserted into positions such that the sum of the voltages shown by the markings is as nearly as possible equal to the normal working voltage of the local supply mains. It is important that the two screws are tightened firmly by finger pressure but not over-tightened by the use of a tool.

3. It often happens that the normal working voltage available in a laboratory or Test Room differs from the nominal supply voltage quoted for the premises. For example, the actual voltage available for the greater part of a working day may be only 230 Volts, although the premises are nominally rated as 240 Volts. In such case the voltage selector screws for the power supply unit should be set as nearly as possible to the lower actual voltage rather than to the higher nominal voltage.

4. It will be noted that the voltage selector screws permit changes to be made in steps of 5 Volts. If the actual working supply voltage lies between two available settings the screws should be set to the nearest lower voltage, to ensure that the power supply unit will maintain its full rated performance during transient drops in the supply voltage.

5. The advice given in the preceding two paragraphs is not to be interpreted as an invitation to operate the power supply unit with the voltage selector screws set to grossly wrong values. If the mains supply voltage is found to vary over abnormally wide limits during the course of a working day, the supply wiring and distribution should be investigated. The advice given above is based on the fact that the use of a pre-stabilizer circuit in this power supply unit makes the unit more tolerant of small excess voltages than a conventional unit, whereas like all power supply circuits, good performance cannot be obtained if the supply voltage is excessively low.

Mains connector

6. The mains connector lead supplied with the unit consists of a plug connected to a 6-ft length of 3-core cable. Switching and fusing within the power supply unit is single pole only and it is important to ensure that the live and neutral lines are correctly connected. It is also essential that

the protective earth connection shall be made via the third (green) conductor. The colours used in the cable are the usual standard ones, as follows.

Mains live	...	Red.
Mains neutral	...	Black.
Earth	...	Green.

Mains fuse

7. The mains fuse F1 is a 5/8" x 3/16" cartridge fuse of 2.5A rating and is situated at the rear of the unit immediately to the right of the mains input plug. Before putting the unit into service check that the fuse is intact and correctly rated and that it is screwed home securely into its holder.

Rectifier fuse

8. The rectifier fuse F2 is a 5/8" x 3/16" cartridge fuse of 2.5A rating and is situated at the rear of the unit immediately to the right of the mains input plug and below the mains fuse F1. Before putting the unit into service check that the fuse is intact and correctly rated and that it is screwed home securely into its holder. This fuse is fitted to guard against failure of a rectifier and is not expected ever to blow in normal service.

Mains switch and indicator

9. The mains switch SW1 is a light action toggle switch fitted centrally on the front panel and is put to the ON position by applying pressure to the lower part of the toggle. The switch has one pole which closes the a.c. mains supply circuit and a second pole which closes the d.c. output circuit of the stabilizer.

10. The indicator lamp is a sub-miniature LES lamp which illuminates the red window in the maker's name plate situated directly below the meter. The lamp indicates that the mains supply is on. For replacement instructions see Section 4.

Voltage controls

11. The output voltage of the unit can be varied over the range 0-50 Volts by means of the two controls on the left-hand side of the front panel. The upper control is a potentiometer (RV4) which covers a range of 10 Volts and the lower control is a 5-position switch (SW2) which changes the output voltage in 10 Volt steps.

12. An internal pre-set control, RV5, is used to set up the system so that the voltage increments produced by the voltage range switch are of 10 Volts per step and the continuously variable control covers a range somewhat greater than 10 Volts in order to allow for circuit tolerances. Because of this there is a slight overlap on each range, making it possible to set the same output voltage either at the upper end of one range or at the lower end of the next higher range.

Metering

13. The meter is a 4 inch rectangular model scaled 0-50 Volts on the upper scale and 0-1 Amp on the lower scale. The associated meter switch, SW5, should be set either to VOLTS or AMPS, as desired.

14. Internal pre-set controls, RV2 for current and RV3 for voltage, are provided for setting the meter calibration and are normally set up in factory test to give correct meter readings at full scale deflection. The accuracy and linearity of the meter are to BSS.89 and the errors at readings below full scale deflection should be negligible for normal purposes.

15. The mechanical zero setting of the meter should be checked with the power supply unit switched off. When in the current metering position there is a small internal current of about 5 mA flowing in the meter circuit; the offset produce by this current is negligible for normal purposes.

Overload protection

16. The sensitivity of the overload protection system can be varied by means of the 6-position Trip Current switch (SW3) on the lower right of the front-panel. The nominal trip current levels which can be selected by this switch are 0.2A, 0.4A, 0.6A, 0.8A, 1.0A and 1.2A.

17. The provision of a 1.2A setting on the Trip Current switch, representing an overload of 20% with respect to the nominal full load current rating of the unit, does not imply that the unit is intended to be operated at currents higher than the full load rating of 1.0A, though in fact no harm will be caused by overloading to this extent provided that the unit is operating at an ambient temperature not above 30°C (the normal maximum temperature rating is 40°C). The reason for providing the 1.2A setting is to ensure that the unit can be operated at its full load current of 1.0A without the overload setting being set so critically that the unit might trip out on a minor and transient overload.

18. The characteristics of the overload protection circuit are that it provides almost instantaneous current limiting action at the approximate

value of current set on the Trip Current switch, followed by delayed trip-out action which cuts off the stabilizer circuit completely. The delay in the trip-out action depends upon the magnitude of the overload and on other operating conditions and can be somewhere in the range 100-500 milli-seconds.

19. If the unit trips out as a result of an accidental overload it can be brought back into service by pressing the Reset push-button in the centre of the front panel, provided that the overload has been removed. If the Reset push-button is pressed while an overload exists, no harm will be caused but the unit will not reset; this is true even if the Reset push-button is pressed repeatedly.

20. The characteristics of the overload protection system have been decided upon as a consequence of discussions with a large number of power supply users, as being the best compromise for a general-purpose unit which is intended mainly for laboratory, test room and class room use. The reasons for the choice of these characteristics are as follows.

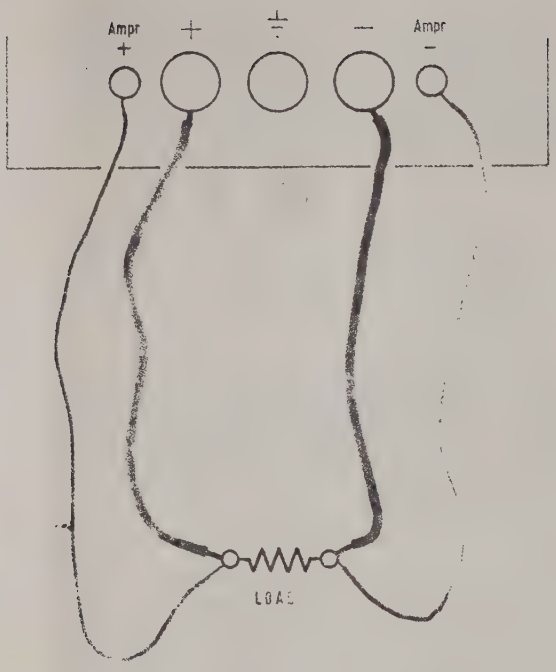
(a) Instantaneous current limiting action is needed to prevent large fault currents which could damage the power supply unit and the user's equipment.

(b) The trip-out action is provided because it is generally undesirable to allow a fault current, even though limited, to continue to flow indefinitely until the user has appreciated that a fault exists and has rectified it. Most of the overloads which occur in normal use are the results of accidents and it is convenient to have the power supply unit cut off until the fault is located.

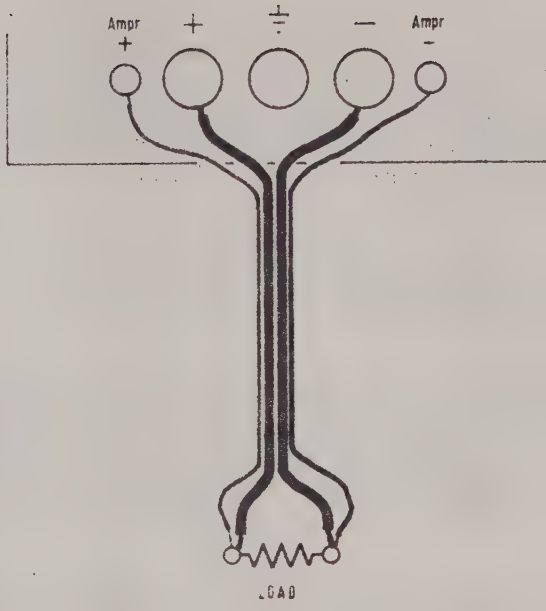
(c) The trip action is delayed, rather than instantaneous, because it is common to find that the user's external equipment may have quite large values of capacitance connected directly across the supply. Many of the fast-acting trip circuits used with some power supplies are difficult or impossible to switch on in such circumstances.

21. The delay in the action of the trip-out circuit has been chosen on the basis that the user's external equipment may have as much as 1000 microfarads of capacitance shunted across a load which will draw a mean current of 1.0A at 50 Volts. The time delay circuit is proportioned so that the power supply unit will switch on or reset after an overload in a reliable manner under these worst case conditions.

22. This power supply unit has no thermal compensation for the overload protection system and it tends to become more sensitive as the ambient temperature increases. The nominal ratings of the Trip Current switch are based on an ambient temperature of 20°C and the sensitivity of the circuit increases at approximately 0.5% per °C. Thus at an ambient temperature of 40°C the sensitivity will have increased such that the overload action commences at a current about 10% lower than at 20°C. It will be noted that this still permits the unit to deliver its full rated current of 1.0A at 40°C but that the trip-out will occur at only 110% of the full load current, instead of 120% at 20°C.



DIAG. 1.



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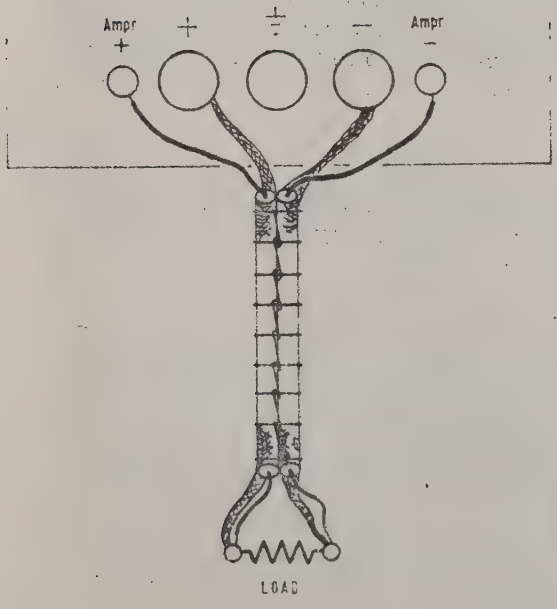

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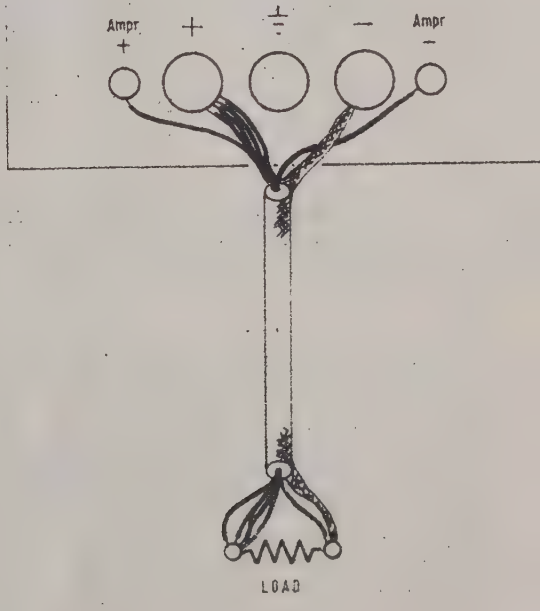


DIAG. 4.

23. Although the characteristics of the present system are believed to be the best for general-purpose use it is appreciated that some users may have applications for which alternative characteristics are desirable. The circuit arrangement is such that special models can readily be supplied with modified characteristics, or advice can be given to enable the user to make the necessary modifications.

Remote sensing

24. The input terminals of the voltage comparator amplifier are brought out to separate sockets on the front panel, adjacent to the output terminals. This facility allows the voltage to be sensed at the actual load, rather than at the output terminals, thus reducing the effects of resistance in the connecting leads from the power supply unit to the load.

25. The need for this facility is much less in a general-purpose power supply unit than in a unit for a fixed installation, since it is usually possible to keep the arrangement and lengths of the connecting leads such that their voltage drop is insignificant. For this reason, and because it would be a nuisance always to have to make separate connections to the amplifier sockets, the sockets are linked to the output terminals by low-value resistors inside the unit. For most normal applications it is possible to use the unit by connecting the load to the output terminals and ignoring the amplifier sockets, the resulting loss of performance being very minor.

26. In cases where the output impedance of the power supply is to be kept to the minimum it may be necessary to use the remote sensing method. If it is only the d.c. resistance which is important the actual layout of the connecting leads will be unimportant but if considerations of a.c. impedance and output ripple are important it will be necessary to dispose the connecting leads with some care.

27. These factors are illustrated by the adjacent diagrams. Diag.1 shows the arrangement with the connecting leads carelessly disposed, leading to the following disadvantages:

(a) The large loop formed by the high current conductors to the load inserts extra inductance in series with the load. If the load current is subject to fast variations this can make the transient response of the power supply unit appear to be very poor. The importance of this factor is more readily appreciated when it is realized that a change of load current at the rate of one Ampere per microsecond, which is not uncommon, produces an inductive e.m.f. of one Volt in a loop circuit with a self inductance of only one microhenry. The use of the remote sensing connections under such conditions can result in the voltage comparator amplifier being severely overloaded transiently and the overall transient response of the system thus becoming even worse.

(b) The large loop formed by the remote sensing leads can pick up considerable electro-magnetic interference from surrounding stray fields, producing abnormally high output ripple or noise.

28. Diag.2 shows how the loop inductances are minimized by bringing all the leads together in a tight group. If strong external fields exist there can be further advantages in twisting or transposing the leads.

29. Diag.3 shows another useful way of connecting to an external load. In this arrangement use is made of two lengths of insulated coaxial cable laced together. The outer screens of the cables are used for the heavy current connections to the load and the two inner conductors are used for the remote sensing connections to the amplifier sockets. A standard 6 ft connector assembly using this principle is available on request.

30. Diag.4 shows yet another possible arrangement. This uses a length of multi-cored cable with an outer collective screen. The screen is used as one of the heavy current connections to the load and all but two of the inner cores are joined together to form the other heavy current connection. The remaining two inner conductors are used for the remote sensing connections to the amplifier sockets.

31. Within the power supply unit the wiring layout is arranged to keep the loop self-inductances to a minimum and the circuit design is such that the output impedance is low and the transient response is very good. The very high performance which the unit can provide to a load connected directly to the output terminals can be degraded appreciably by even quite short connecting leads if these are badly disposed.

32. That the performance of the unit depends upon the way in which the connections are made to the load is not a defect in the design of the unit. The problem is simply that the power supply unit, the load and the connections between them are all parts of a high-gain feedback loop and, as is well known, there are strict limitations as to how far it is possible to correct for deficiencies by the use of feedback.

33. As a general guide to the use of the remote sensing facility, the following are recommended limitations:

(a) The total volt drop at maximum load current in the heavy current conductors should not exceed 0.5 Volt for the complete loop circuit.

(b) The resistance of each of the two remote sensing connections to the amplifier sockets should be kept as low as possible, preferably not greater than 0.1 Ω and in extreme cases even lower.

Use as a 'floating' supply

34. This power supply may be used as a 'floating' supply, i.e. with neither output terminal connected to or at earth potential. The only limitation in this mode of use is that neither output terminal should be more than 500 Volts d.c. above or below earth potential.

35. When operating as a floating supply it may be found that the output ripple is slightly higher than when one of the output terminals is directly earthed. This can be rectified by connecting a moderately low 2 impedance d.c. blocking path from one output terminal to earth. It is not possible to give firm recommendations in this respect because the conditions depend upon the particular application. The increase in output ripple under floating conditions is, in any case, minor.

Series connection of power supplies

36. This power supply unit is designed so that it may be connected in series with other power supplies, in cases where a higher output voltage is required than can be obtained from a single conventional unit. The only limitations to be observed in this class of service are as follows:

(a) Neither output terminal should be operated at more than 500 Volts d.c. away from earth potential.

(b) It should be checked that the load current drawn from a series cascade of power supply units is not greater than the full load rated current of the unit with the lowest current rating.

37. The power supply unit has a semi-conductor diode connected directly across its output terminals, so that the unit is protected from harmful reverse voltage or current if it is accidentally switched off while operating in series with other power supply units. Special attention is drawn to the warning in the following paragraph.

38. WARNING It is possible for the semi-conductor diode MR13 across the output terminals to be damaged if the power supply unit is being operated in series with other power supply units which are capable of delivering very large output currents under fault conditions. For series operation of power supply units it is desirable to ensure that all the power supply units are fitted with effective overload protection circuits and that these are set to operate in the same current range for all the units.

Parallel connection of power supplies

39. Due to its low output resistance and highly stabilized output voltage, this power supply unit is not suitable for operation in parallel

with other stabilized power supply units. If this type of operation is attempted it will be found that the slightest difference in output voltage between one unit and the other will result in one of the units carrying the whole of the load current.

40. No provision for parallel operation is made in any power supply units of the TCU family because the complexity and cost of the extra switching and wiring is impossible to justify. The ability to operate power supply units in parallel was a feature of early designs of transistor power supplies, when only very low current ratings could be offered in a single unit. Now that high current ratings are commonplace the provision of a paralleling facility is rarely required.

Switching characteristics

41. Particular care has been taken in the design of this power supply to ensure that there are no abnormal voltage transients when switching the unit on or off, or when resetting the overload protection system after an accidental overload. In general it will be found that the voltage rises cleanly to the set value when the unit is switched on or reset and falls cleanly when the unit is switched off. This is so even at the very lowest output voltage settings.

42. It is possible, however, under a very rare and adverse combination of circumstances involving mains voltage transients, switching at an adverse instant in the mains cycle and switch arcing, that a very momentary overvoltage could occur. If this does happen, and it is extremely rare, the magnitude of the transient excess voltage is greater, expressed as a percentage of the set voltage, when the set working voltage is very low. This point should be remembered if it is necessary to work at very low output voltages with load circuits which include abnormally fragile devices that might be damaged by transient excess voltage.

Operation with pulsed or switched loads

43. The power supply unit is suitable for use in applications in which the load current is subject to rapid variations, as in circuits in which the load is subjected to switching or pulse modulation, and the transient response characteristics of the power supply have been selected accordingly. In this type of operation there are certain matters which require attention.

44. It is a characteristic of transistors in general that they are charge operated devices, so that it is necessary to inject or subtract a certain amount of excess charge in the base circuit in order to bring about a change in the collector current. This is the cause of the finite 'turn-on', 'storage' and 'turn-off' times quoted for transistors when operating in a switching mode. This factor is particularly relevant to transistorized power supply units when operating in switched or pulsed loading conditions.

45. The effect is most significant in the power transistor in the series regulator circuit and gives rise to the following effects:

(a) If the power supply is initially delivering only a small output current and there is a sudden demand for a larger current, even an instantaneous change in base current or potential cannot force the power transistor to pass the increased collector current instantaneously. During the short 'turn-on' period the extra load current has to be derived from the capacitor across the output terminals and there is a consequent transient fall of output voltage.

(b) If the power supply is initially delivering a large output current and there is a sudden reduction in the load current, the series regulator transistor cannot instantaneously be forced to deliver a reduced collector current. During the short 'turn-off' period an excess current is delivered to the output terminals and stored in the shunt capacitor, so that there is a transient rise of output voltage.

46. These undesirable effects can be reduced by using a high-speed switching type of transistor for the main series regulator but such devices are abnormally expensive. In the present unit a germanium power transistor of only moderate performance is used but careful design of the circuits has made it possible to achieve a highly satisfactory transient response.

47. Effects of the type discussed in para.45 above depend upon the magnitude of the change in load current rather than the actual mean load current level, particularly with regard to para.45(b). For this reason the best possible transient response is obtained when the variable part of the load current is only a small proportion of the total mean load current. If work is being done on a circuit which draws an impulsive load current and freedom from voltage transients is important, it is advisable to put an additional fixed load resistor across the output terminals of the power supply unit such that the peak current drawn from the unit approaches the full load rating of the unit; attention should also be given to the remarks in para.24 et seq., concerning the inductance of connecting leads.

48. When operating into a load circuit which draws current in short-duration pulses it is important to remember that the overload protection system may come into action on excessive current peaks even though the mean current shown on the meter is below the maximum rating of the unit. With loads of this nature it is possible for the power supply unit to be heavily overloaded on current peaks without tripping out the overload protection system. This will cause no damage but will make the power supply unit appear to have poor regulation and transient response.

49. If the power supply unit appears to have bad regulation and to exhibit serious voltage transients when operating into an impulsive type of load circuit it is necessary to check the magnitude of the peak current being drawn from the supply and to make sure that the power supply unit is not in fact being overloaded.

TECHNICAL DESCRIPTION

GENERAL

1. The circuit arrangement consists of a conventional transistor series regulator circuit fed with pre-stabilized d.c. from an SCR pre-stabilizer of novel design.

2. The main power transistors are Germanium types but all other transistors are Silicon. The circuit includes a number of design features aimed at improving stability and transient response. The overload protection circuit is of a dual type which combines instantaneous current limiting with a delayed trip-out action.

3. The circuit is best described by considering each of the various sections separately, as follows.

TRANSFORMER-RECTIFIER SYSTEM

4. The power transformer T1 is of core-type construction using a C-core loop and having carefully balanced mutual impedance characteristics. Various secondaries on the transformer feed the various rectifier systems, as described below. The primary winding of T1 is provided with tappings to accommodate different mains supply voltages, and is fed through switch SW1a and fuse F1.

Auxiliary Rectifier No.1.

5. Secondary No.1 on transformer T1 provides 25 Volts r.m.s. nominal to the full-wave bridge rectifier MR1, the output of which is smoothed by resistor R2 and capacitor C1. The smoothed d.c. output from this circuit is used in the voltage comparator part of the stabilizer system, as described in para.22.

Main Power Rectifier

6. Secondary No.2 on transformer T1 is a tapped high-current winding which feeds the full-wave bridge rectifier formed by MR5, MR6, MR7 and MR8, through the voltage range switch SW2a and the fuse F2. The output from this rectifier system is applied to the output terminals of the unit through the series regulator transistor VT5.

Auxiliary Rectifier No.2.

7. Secondary No.4 on transformer T1 provides 25-0-25 Volts r.m.s. nominal to the full-wave bridge rectifier MR2. The arrangement of this rectifier is such that it is really a combination of two separate biphase rectifiers, providing separate positive and negative outputs with respect to the centre tap of secondary No.4.

8. The positive output from MR2 is smoothed by resistor R3 and capacitor C2, the smoothed d.c. output being used for the following purposes.

(a) To provide reverse base bias current for transistors VT4 and VT5 in the series regulator circuit.

(b) To provide a positive supply for the pre-stabilizer circuit.

(c) To provide a positive supply for the voltage comparator part of the stabilizer system.

9. The negative output from MR2 is smoothed by resistor R4 and capacitor C3 and is used to provide a negative supply for the stabilizer and overload protection circuits.

10. Secondary No.4 of transformer T1 also feeds two rectifier diodes MR3 and MR4 but these are associated with the pre-stabilizer circuit and are described in para.15(c) and para.16.

PRE-STABILIZER SYSTEM

11. The pre-stabilizer circuit uses the Silicon Controlled Rectifier SCR1 to switch the output of the main power rectifier to the filter capacitor C11, the instant of firing of the SCR being varied in accordance with prevailing operating conditions in order to maintain the mean voltage across C11 at the desired value.

12. The basis of control of the pre-stabilizer is that the circuit measures the voltage in the emitter-collector circuit of the series regulator transistor VT5 and controls the firing of SCR1 in a manner such as to hold this voltage across the transistor circuit at a substantially constant level, despite variations in mains supply voltage, output voltage or output current.

13. The advantage of controlling the emitter-collector circuit voltage of VT5 in this manner is that it minimizes the power dissipation in the transistor by automatically adjusting the circuit voltage to the minimum compatible with satisfactory performance. The use of this circuit makes it possible to vary the output voltage over a considerable range without appreciable change in the voltage or power dissipation of VT5.

14. SCR1 is fired by the positive pulse from the blocking oscillator transformer T2 in the collector circuit of transistor VT2. VT2 is arranged to serve both as a voltage comparator circuit and a blocking oscillator pulse generator and it remains quiescent whenever its base potential is less than about 0.5 Volt positive with respect to its emitter. If the base potential is raised above this figure however, VT2 regenerates as a blocking oscillator and delivers a train of positive firing pulses to the gate circuit of SCR1. Resistor R59 in series with the SCR gate is used to limit the peak gate current which can flow.

15. The input control signal at the base of VT2 is the potential across capacitor C9, which consists of the following components.

(a) A positive-going sawtooth waveform at twice the mains supply frequency, produced by the sawtooth generator VT1 as described below and applied to C9 through resistor R13.

(b) A positive bias from the +9V stabilized auxiliary supply from zener diode ZD2, applied to C9 through resistor R15.

(c) A negative-going rectified sine wave signal produced by diodes MR3 and MR4 and applied to C9 through resistor R14.

(d) The negative voltage at the collector of the series regulator transistor VT5, applied to C9 through the filter system comprised of R16, C8, R18, R17, R19 and C10. This filter network modifies the control signal to give optimum response characteristics to the pre-stabilizer control.

16. The sawtooth generator VT1 acts as a switch to permit capacitor C6 to be charged periodically through resistor R6-RV1 and then discharged rapidly at the end of each charging cycle. The control signal at the base of VT1 is the rectified sine wave produced by diodes MR3 and MR4, attenuated by R8 and R9 and applied to the transistor base through capacitor C4. The resistor R7 provides positive bias to the base of VT1 to ensure that the transistor conducts heavily at the instants at which the a.c. signal at the base passes through its zero values.

17. The complex waveform applied as a control signal to the base of VT2 causes the blocking oscillator to fire at a time in the supply cycle which is such that SCR1 acts as a stable voltage regulator and tends to maintain the mean voltage at the collector of VT5 measured with respect to the negative output terminal of the power supply unit at a substantially constant level. The variable pre-set resistor RV1 varies the amplitude of the sawtooth waveform component and thus allows the voltage at the collector of VT5 to be set to its correct value (about 5 Volts) despite variations in circuit and component tolerances.

STABILIZER SYSTEM

18. The stabilizer system is a quite conventional arrangement of the series regulator type. The series regulator transistor VT5 is in series with the output line to the load circuit and is controlled by the voltage comparator amplifier system through the compound emitter-follower stages VT3 and VT4.

19. The power transistor VT5 and its driver VT4 are both Germanium types and provision is therefore made for reverse base bias current from the +20V auxiliary supply, applied through resistors R23 and R24. Sufficient bias current is available to compensate for the worst case leakage currents which could flow under conditions of high junction temperature and high applied voltage. This arrangement ensures that the series regulator system can be cut off completely under overload fault conditions, even in the most adverse of operating conditions.

20. The voltage comparator amplifier consists basically of the two transistors VT8 and VT10, arranged in the low-drift emitter-coupled configuration. The amplifier compares the voltage across the reference zener diode ZD1 with a selected fraction of the output voltage from the power supply unit, so that any deviation of the output voltage from the set value causes an error signal to appear at the collector of VT10. This error signal is further amplified by VT9 and is then applied as a control signal to the base of VT3. The overall effect is to produce a high-gain, low-drift degenerative control loop.

21. The output voltage is determined by the resistor network in the base circuit of VT10, consisting of the range-changing resistors R51 to R54, the fine voltage control RV4, the pre-set adjuster RV5 and resistor R55. The network forms an adjustable potential divider which permits the actual output voltage from the power supply unit to be reduced to approximately 5.6 Volts, at which level it can be compared by balancing against the voltage across the reference zener diode ZD1.

22. Because the voltage comparison is made at a level of 5.6 Volts, whereas the output voltage of the power supply unit is to be controllable down to zero, it is necessary to use an auxiliary reference potential of 5.6 Volts in the potential divider chain. This auxiliary reference potential is obtained from across zener diode ZD4, fed from the output of auxiliary rectifier No.1 through the pre-stabilizer section formed by resistor R46 and zener diode ZD3.

23. The pre-set adjuster RV5 is provided to standardize the current in the potential divider network to a value such that the output voltage will change in exactly 10 Volt steps as the voltage selector switch SW2 is operated to switch resistors R51 to R54 into or out of circuit. RV5 is pre-set during initial alignment of the power supply unit and should not require further adjustment unless components are changed.

24. In common with all high-gain feedback systems, this circuit has a natural tendency to self-oscillation and it is necessary to modify the gain/phase characteristics to ensure stability under all possible working conditions. The components involved are C16, R42, C17, R56 and C19, the values of which have been chosen to give complete stability combined with the best possible transient performance. Capacitor C20 across the output terminals of the power supply unit also has a significant influence on stability and transient response.

25. The diode MR13 connected across the output terminals plays no part in the normal operation of the unit but is fitted for the following purposes

(a) The diode prevents any significant reversal of polarity of output voltage when the unit is in the 'tripped-out' state following an accidental overload.

(b) If two or more power supply units are being operated in series to provide a higher output voltage than can be obtained from a single conventional unit, and if the present power supply unit is accidentally switched off, the diode bypasses the current which flows due to the remaining active power supply units and protects the 'off' unit from damage.

26. The diode MR12 connected between the collector of VT10 and the negative output terminal of the unit is fitted to protect transistor VT9 from excessive overloads which may occur during switching operations or when operating with heavily pulsed loads. The purpose of MR12 is not to protect VT9 from actual damage, since this could not occur, but to prevent temporary paralysis of the amplifier stages which could result in excessive output voltage transients.

27. It will be seen that a second pole of the mains switch SW1, SW1b, is placed in series with the positive line from capacitor C11 to the positive output terminal. This switch is provided to disconnect the external load circuit whenever the power supply unit is switched off, and is required mainly to deal with conditions which might arise when the power unit is being operated at a very low output voltage and with negligible load current. Under such conditions the capacitor C11 will discharge much more slowly than the capacitors in the auxiliary rectifier circuits and but for the extra switch contact SW1b it would be possible for the output voltage to rise above its set value at some time after the switching off of the unit.

OVERLOAD PROTECTION SYSTEM

28. The total output current of the unit passes through the meter shunt resistor R50 and such of the resistors R29 to R33 as are in circuit by reason of the setting of the trip current switch SW3. As a consequence of these resistors the emitter of transistor VT5 will be negative with respect

to the negative output terminal of the unit by an amount which is proportional to the output current and to the total value of the included resistance. The fault protection system comes into operation when the emitter of VT5 reaches a potential of about -0.6 Volt.

29. Resistor R50 has a value such that a voltage drop of 0.6 Volt is produced by a current of 1.2 Amps, i.e. 120% of the maximum rated output current of the unit. Thus when R50 alone is in circuit the trip current setting is 1.2 Amps.

30. Additional resistors R29, R30, R31, R32 and R33 can be switched into circuit by SW3 and the values of these resistors are chosen so that the current required to produce a potential of -0.6 Volt at the emitter of VT5 can be reduced to 1.0A, 0.8A, 0.6A, 0.4A and 0.2A. These calibrations are approximate, there being no requirement for high accuracy in general purpose applications. Also, there is a tendency for the sensitivity of the protection circuit to increase with increasing ambient temperature due to the fall in V_{be} of transistor VT7; it is possible to correct for this effect but for the present design the effect is regarded rather as an advantage in that it provides increased protection against misuse.

31. The essential part of the overload protection system consists of transistor VT7 and its associated components. The potential at the emitter of VT5 is applied to the base of VT7 through the potential divider R28, R37, so that VT7 commences to become effectively conducting when the potential at VT5 emitter reaches -0.6 Volt.

32. For output currents below the critical value VT7 is non-conducting (or only slightly conducting) and its collector potential is considerably more negative than the normal working potential at the junction of resistors R43 and R44 in the collector circuit of VT9 in the stabilizer system. Under these conditions the diode MR11 is reverse biased and conditions in the VT7 circuit can have no influence on the operation of the stabilizer system.

33. When the output current reaches or tries to exceed the critical value determined by the setting of the trip current switch SW3, VT7 becomes sufficiently conducting to raise its collector potential above the normal working potential at the junction of R43 and R44. Diode MR11 now becomes forward biased and clamps the collector of VT9 to the collector of VT7. The effect of this is that the normal voltage comparator amplifier action in the stabilizer system is put out of action and VT7 takes over control of the base potential of VT3 in a manner such as to convert the circuit into a constant current system.

34. This current limiting action is virtually instantaneous, although there is a very slight delay action caused by capacitor C15. The sole purpose of C15 is to prevent a form of instability which can occur when the power unit is being operated under pulsed loading conditions at the very extreme of its current rating and C15 has no real function in the normal operation of the overload protection system.

35. Due to the use of a pre-stabilizer system it would be possible to use this current limiting action as the sole form of overload protection, since even prolonged operation at the limited current would not cause appreciable excess dissipation in VT5. For general purpose power supply units there is, however, a general demand for a protection system which will 'trip-out' when an overload occurs, rather than to continue to deliver the full load current indefinitely; this extra facility is provided by transistor VT6 and its associated components.

36. VT6 has its emitter held at an intermediate potential by the potential divider R25, R26 and its base is returned to the collector of VT7 through resistors R34 and R38. Under normal (non-overload) conditions VT7 is conducting so slightly that its collector potential is negative with respect to the potential at the junction of R25 and R26, so that VT6 is essentially in a cut-off state. There is then no fall of potential across R27, so that diode MR10 is non-conducting and there is no interference with the normal operating conditions in the base circuit of VT7.

37. When an overload condition occurs, the potential at the collector of VT7 rises sufficiently to bring VT6 to the conducting state and there is a fall of potential across R27. This causes the diode MR10 to conduct and pull down the potential at the base of VT7 even further. The action is cumulative and the circuit triggers into a state in which both VT6 and VT7 are conducting. The rise in potential at the collector of VT7 raises the potential at the base of VT3 to a level at which the series regulator system is completely cut off and the system will remain in this state indefinitely, until it is reset.

38. The regenerative action between VT7 collector and the base of VT6 is not instantaneous, being delayed due to the charging time-constant of capacitor C14 through resistor R38. This delay action is introduced so that the overload system will always give a short period of current limiting action before finally tripping out completely. The reason for this delay, and the factors which determine its duration, are discussed in Section 2, para.21.

39. The overload system is reset after an overload by pressing the reset switch SW4. This places the initially uncharged capacitor C13 between the -15 Volt auxiliary supply and the junction of resistors R34 and R38, so that the charging current of C13 forces transistor VT6 into the non-conducting state for a short period, thereby breaking the regenerative loop formed by VT6 and VT7. If the circuit state is such that no overload now exists, this action will restore the system to normal operation. When SW4 is released the capacitor C13 discharges through resistor R35 in readiness for the next time it may be required.

40. If the reset switch SW4 is pressed while an overload state still exists in the stabilizer circuit, the charging of C13 will for a short period permit VT6 to be cut off and VT7 to restore the stabilizer circuit to the current limited mode. No damage will be caused by this and the effect is of short duration, limited by the charging time of C13. Repeated attempts to reset the system while an overload exists will have no ill effects.

METERING CIRCUITS

41. Metering is obtained by the meter M1, which has a sensitivity of 1 mA for full scale deflection. The meter is switched through SW5, to read either Volts or Amperes.

42. In the Volts setting of SW5 the meter is put in series with resistor R48 and preset adjuster RV3, across the output terminals of the power supply. RV3 is set up for correct meter calibration during initial alignment of the unit.

43. In the Amps setting of SW5 the meter is put in series with resistor R49 and preset adjuster RV2, across the meter shunt resistor R50. RV2 is set up for correct meter calibration during initial alignment of the unit.

SECTION 4

MAINTENANCE AND REPAIR

General

1. The components and the circuit design of this power supply unit are such that years of satisfactory life may be expected without need for maintenance or repair action. Nevertheless, component failures can occur and it is possible for damage or misadjustment to arise from careless or improper use. The following notes are given to cover such contingencies.

Indicator Lamp

2. The indicator lamp is protected from premature failure by being operated from an 8 Volt supply through a current limiting resistor, thus protecting the lamp from the very heavy switching on currents which are the principal cause of premature lamp failure.

3. If the indicator lamp does not light, though the power supply unit is otherwise in normal operating order, the possibilities are as follows

(a) The lamp may have worked loose in its holder.

(b) The lamp may have failed.

(c) Resistor R1 may have become high-resistance or open-circuit.

(d) There may be a broken wiring connection.

4. The indicator lamp is mounted in a miniature lamp-holder on the rear of the maker's nameplate, immediately below the meter. The nameplate can be removed to give access to the lamp. The nameplate is located on the front panel by three spigots, one at each end and one slightly to the left of the centre, the latter being gripped by a spring retainer clip on the inside of the front panel.

5. To remove the maker's nameplate, grip it firmly at each end with the finger nails under the edge of the plate and pull gently outwards. If the spring retainer clip tends to grip the centre of the plate too firmly to permit release, a small screwdriver or other tool can be inserted under the plate near to the centre and used to lever the plate outwards. If a tool is used, care should be taken not to scratch the front panel.

6. When the maker's nameplate has been released it can be pulled outwards away from the front panel sufficiently to allow the lamp to be examined or replaced. When replacing the nameplate, care should be taken to ensure that the connecting leads to the lamp are not trapped between the nameplate and the front panel and that the lamp and lampholder pass easily through the slot in the front panel. Position the nameplate so that its three spigots align with the holes in the front panel and then press the nameplate home firmly with an even pressure.

7. If examination of the lamp does not disclose the fault it will be necessary to remove the case from the unit to permit further examination internally.

Removing the case

8. To remove the case from the unit, disconnect all leads and unplug the mains connector. Place the unit face downwards on a clean flat surface and remove the four screws which secure the case. The case may then be lifted upwards away from the unit.

Meter calibration adjustment

9. If the meter calibrations are suspected of error, first check that the mechanical zero of the pointer is correct. This should be checked with the power unit switched off and standing erect on a level surface. After adjustment of the mechanical zero the power unit should be switched on and tested at various output voltages and currents against external meters of known accuracy.

10. The internal adjusters for the meter calibrations are accessible when the unit is removed from its case, the two adjusters being mounted at the extreme top of the printed circuit amplifier card. During calibration at Works these adjusters are sealed by a small dab of quick-drying plastic adhesive but this can readily be broken if re-adjustment is required.

11. Re-adjustment of the meter calibrations should preferably be carried out at the full-scale deflections of the meter, i.e. at 50 Volts and at 1.0 Amp. When resetting an adjuster, make sure that the connecting lead to the slider is not under stress which could cause subsequent movement and then secure the slider assembly to the insulated back plate of the adjuster by a small dab of adhesive. Great care should be taken to ensure that no adhesive is allowed to come into contact with the resistive element.

Voltage range adjustment

12. If the unit appears not to be covering its correct output voltage ranges, a check should first be made that it is not a meter calibration error. The output voltage and current should be checked against external meters of known accuracy. If the meter calibration is correct, note whether the errors in the voltage range adjustment are minor or serious, and then proceed as follows.

13. If the errors are minor it may be that the preset adjuster has become displaced and requires resetting. This can be checked as follows

(a) Set up the unit for normal operation and connect an oscilloscope to the output terminals to monitor the output ripple. The tests can be made with no external load. The purpose of the oscilloscope is to ensure, by observing that the output ripple remains very low at all output voltage settings, that the stabilizer circuit is regulating correctly. If a high output ripple (more than say one millivolt peak to peak) were to appear it would indicate that the stabilizer was partially or completely out of action and this could be the reason for the wrong voltage range coverage.

(b) If under these test conditions the output ripple remains low at all output settings but the voltage coverage is slightly wrong, set the voltage selector switch to its lowest range and check the output voltage range covered by the fine voltage control. This control should vary the output voltage from just below zero to just above 10 Volts. If the fine voltage control will not allow the output voltage to be reduced to zero or slightly below, refer to para.14. If the fine voltage control will control the output voltage down to zero and up to about 10 Volts, proceed as follows.

(c) Set the fine voltage control to make the output voltage exactly zero. Now turn the voltage selector switch to each in turn of the higher ranges and at each setting note the amount by which the output voltage increases. If it is the preset adjuster which is wrongly set it will be found that each step of the voltage selector switch increases the output voltage by the same amount but that this amount is either a little less or a little more than 10 Volts. If this is so proceed as follows, but if not refer to para.15.

(d) The adjuster RV5 is fitted at the lower centre of the printed circuit amplifier card and is possibly accessible from the underside of the unit when the case is removed. If however, the adjuster position is obscured by the adjacent capacitors C20 it will be necessary to lower the front panel away from the chassis, as described in para.18. During alignment at Works the adjuster RV5 is sealed with a small dab of quick-drying plastic adhesive but this can readily be broken if re-adjustment is required.

(e) The adjuster RV5 is re-adjusted by moving its slider, on a trial and error basis, until a setting is found which will cause the successive steps of the voltage range switch to change the output voltage in exactly 10 Volt steps. When this setting has been found, RV5 should be re-sealed. Make sure that the connecting lead to the slider is not under stress which could cause subsequent movement and then secure the slider assembly to the insulated back plate of the adjuster by a small dab of adhesive. Great care should be taken to ensure that no adhesive is allowed to come into contact with the resistive element.

(f) After re-adjusting RV5, as in (e) above, repeat the test for the voltage coverage of the fine voltage control, as described in (b) above. If no other fault than a wrongly set RV5 existed it should now be found that the fine voltage control covers a range from zero or just below to a little above 10 Volts. If this is so the re-adjustment is complete. If, however, the fine voltage control still will not cover a swing greater than 10 Volts, although each step of the voltage selector switch does give a 10 Volt change, the potentiometer RV4 must be faulty and should be tested for possible short-circuiting between turns of its winding.

14. If when carrying out the test described in para.13(b) it is found that the fine voltage control covers a swing of over 10 Volts but will not reduce the output voltage quite to zero when it is turned fully anticlockwise, proceed with the test described in para.13(c) to determine whether there is a fault which is causing seriously incorrect voltage changes when the voltage selector switch is put to its various positions. If no serious discrepancy is noted in this latter test it is possible that one or other of the zener diodes ZD1 or ZD4 has been changed and that a replacement of incorrect voltage has been fitted. The position in this respect is as follows.

(a) Zener diodes ZD1 and ZD4 are both nominally of 5.6 Volts rating but their production tolerances are quite wide. In the present circuit it is necessary to ensure that the zener diode ZD4 has a slightly higher operating voltage than ZD1, in order to ensure that the output voltage of the power supply unit can be reduced to zero.

(b) In production the zener diodes are graded to ensure that the correct relationship exists between ZD1 and ZD4 but if a zener diode is changed by the user this point may have been overlooked.

(c) If there is doubt on this point, measure the voltages across ZD1 and ZD4 with a high-resistance (20,000 ohms/Volt) meter of good reading accuracy and check that ZD4 has a higher voltage than ZD1 by not less than 0.1 Volt. If this condition is satisfied the fine voltage control should be able to control the output voltage down to zero. If, however, the correct voltage difference exists between ZD1 and ZD4 but the output voltage cannot be reduced to zero, there is probably a defective transistor in either the VT8 or VT10 position.

15. If when carrying out the test described in para.13(c) it is found that the voltage selector switch does not vary the output voltage in equal steps, though the oscilloscope indicates that the power unit is continuing to regulate correctly, there is probably a faulty resistor in one of the positions R51, R52, R53 or R54. Which resistor is faulty can be deduced by noting which setting of the voltage selector switch gives the incorrect voltage change.

16. Serious errors in the voltage range coverage of the unit are most probably due to a defect in the voltage comparator amplifier circuit and are likely to be associated with poor stabilization and high output ripple. For faults of this type it is necessary first to check the voltages from the main power rectifier and the two auxiliary rectifier circuits and then to carry out a detailed point to point check of the circuit.

17. A possible fault symptom is that the output voltage of the unit cannot be reduced below about 5.5 Volts on the lowest voltage setting and that the output voltage is about 5.5 Volts higher than it should be on all ranges. This could be due to a failure in auxiliary rectifier No.1 circuit or in the zener diode circuits including R46, ZD3, R47 and ZD4.

Access to the printed circuit amplifier card

18. When the case is removed from the power unit it is possible to obtain access to the components on the printed circuit amplifier card by hinging the front panel of the unit outwards from the main chassis. It will be seen that the front panel assembly is secured to the main chassis by six screws, three at either side.

19. If the upper two screws on each side are removed completely and the bottom screw on each side is slackened, it is possible to hinge the front panel assembly outwards until it is at an angle of ninety degrees to the chassis. This gives complete access to the components on the card and the unit can be operated in this position while tests are made.

20. When replacing the front panel into its normal position it is important to ensure that the cableforms are not trapped between the panel and the chassis. Replace the four upper screws which secure the panel to the chassis and then tighten all six securing screws firmly.

Access to components on the front panel

21. To obtain access to components at the rear of the front panel it is necessary first to hinge out the front panel as described above and then to detach the printed circuit amplifier card. The card is secured to the front panel as follows.

(a) At the top by the two nuts which hold the card to the terminal extension pillars on the rear of the meter.

(b) At the bottom by two screws which secure the card to the two extension pillars at the rear of the output terminals.

22. To lift the card away from the front panel, remove the two screws and the two nuts referred to above and lift the top of the card free of the meter. The card can then be hinged back on its cableforms to give clear access to the components and wiring on the front panel.

23. When replacing the card it is important to ensure that the cableforms are put back into their original positions and that the two screws at the bottom of the card are particularly well tightened; these screws also make the connections to some of the capacitors forming C20, and if there are bad connections at this point the performance of the unit will be impaired.

Access to components on the rear panel

24. The rear panel of the unit, which carries the mains plug, fuses and voltage selectors, also carries a number of components associated with the auxiliary rectifier circuits. The panel is readily removable to allow access to these components.

25. The rear panel is secured to the transformer shield, which projects from the chassis side members, by two screws at each side. Removal of these screws permits the panel to be pulled back sufficiently to give access to the components and to certain of the connections to the mains transformer.

26. When replacing the rear panel, care should be taken to ensure that none of the wiring is disarranged or trapped and that no connections have been moved into positions which could allow them to press on the transformer windings.

Access to components on the heatsink

27. The power transistor VT5 is fitted on the heatsink in a position such that it can be removed or replaced without dismantling the heatsink from the chassis. The SCR, however, is in a position such that it is not possible to replace it without unbolting the heatsink.

28. The heatsink is secured to the two side members of the chassis by four screws which pass through insulated bushings, so that the heatsink is insulated from the chassis. To remove the heatsink, remove the four screws, making sure that the insulated bushings are not damaged or lost. The heatsink can now be pulled away from the chassis sufficiently to give access to the SCR connections and to the components mounted on the chassis behind the heatsink.

29. When replacing the heatsink, the screws and insulating bushings should be re-assembled in exactly the same positions as they had originally. Great care should be taken not to over-tighten the screws to an extent that an insulated bushing might be cracked.

Replacing the mains transformer

30. To replace the mains transformer it is necessary to have access to the connections at both the front and rear, so that the front panel and the rear panel both have to be detached as described above. After the connections have been unsoldered the transformer can be removed by removing the eight screws, four at either side, which hold it into the chassis. The transformer should be removed by drawing it directly upwards out of the top of the chassis.

31. Transformers for these power units are jig-assembled and there should be no difficulty in making a direct replacement. Check that the new transformer is fitted correctly and securely into position and that all connections are soundly soldered. Make sure that the cableforms are replaced exactly into their original positions.

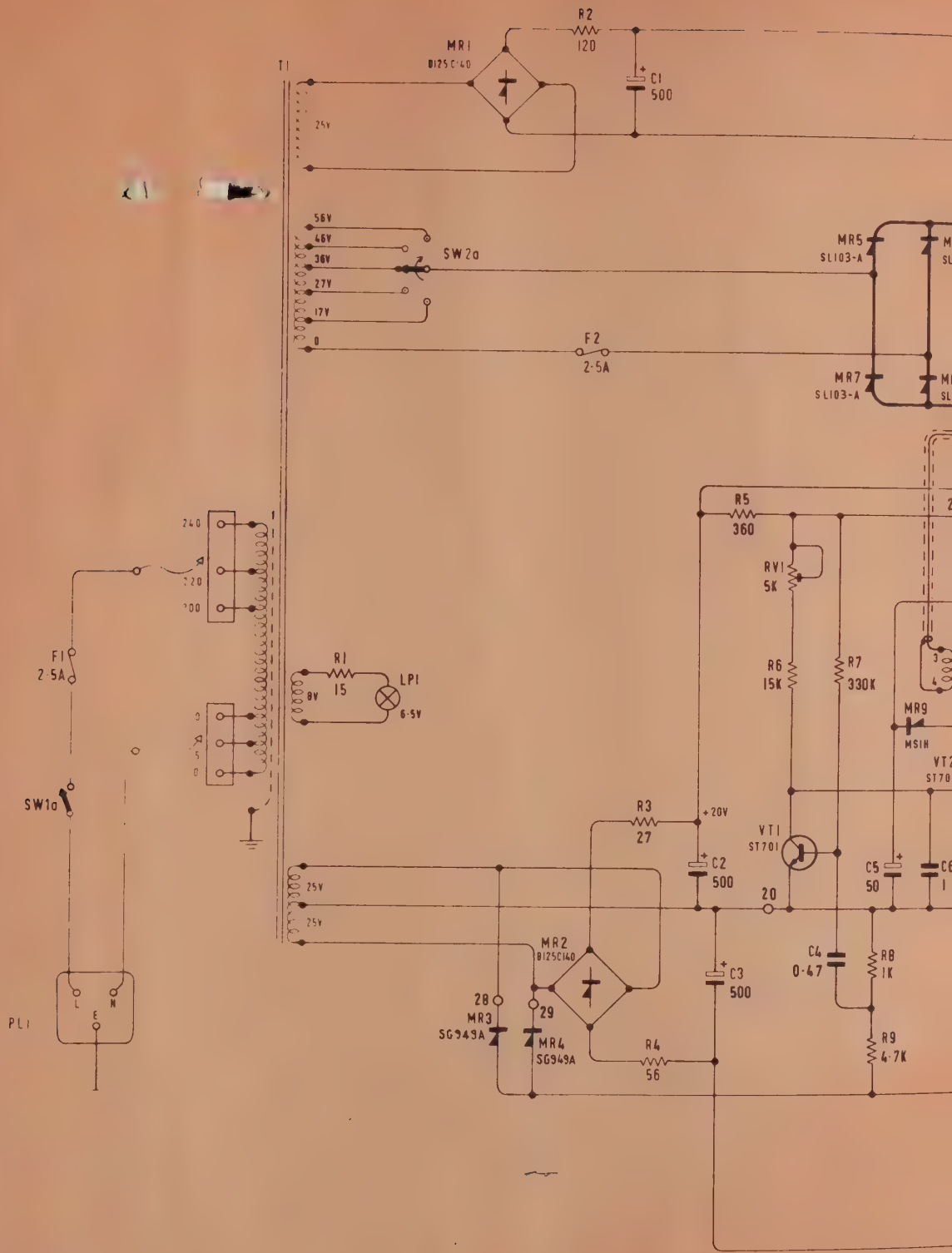
PARTS LIST

Cct. Ref.	Value	Description	Rating	Tol. ± %	Maker and Type
RESISTORS, FIXED					
R 1	15 Ω	Carbon	1/2W	10	Morganite Type S
R 2	120 Ω	High stability	1/2W	5	Welwyn Metox F20
R 3	27 Ω	High stability	1/2W	5	Welwyn Metox F20
R 4	56 Ω	High stability	1/2W	5	Welwyn Metox F20
R 5	360 Ω	High stability	1/2W	5	Welwyn Metox F20
R 6	15 kΩ	High stability	1/2W	5	Welwyn Metox F20
R 7	330 kΩ	Carbon	1/2W	10	Morganite Type S
R 8	1 kΩ	High stability	1/2W	5	Welwyn Metox F20
R 9	4.7 kΩ	High stability	1/2W	5	Welwyn Metox F20
R10	2.2 kΩ	Wirewound	3W	5	Welwyn AW3101
R11	220 Ω	Carbon	1/2W	10	Morganite Type S
R12	150 Ω	Carbon	1/2W	10	Morganite Type S
R13	15 kΩ	High stability	1/2W	5	Welwyn Metox F20
R14	270 kΩ	High stability	1/2W	5	Welwyn Metox F20
R15	39 kΩ	High stability	1/2W	5	Welwyn Metox F20
R16	3.3 kΩ	Carbon	1/2W	10	Morganite Type S
R17	15 kΩ	High stability	1/2W	5	Welwyn Metox F20
R18	15 kΩ	High stability	1/2W	5	Welwyn Metox F20
R19	1 kΩ	Carbon	1/2W	10	Morganite Type S
R20	4.7 kΩ	Wirewound	3W	5	Welwyn AW3101
R21	33 kΩ	Carbon	1/2W	10	Morganite Type S
R22	220 Ω	High stability	1/2W	5	Welwyn Metox F20
R23	3.9 kΩ	Carbon	1/2W	10	Morganite Type S
R24	1 kΩ	Carbon	1/2W	10	Morganite Type S
R25	2.7 kΩ	High stability	1/2W	5	Welwyn Metox F20
R26	2.2 kΩ	High stability	1/2W	5	Welwyn Metox F20
R27	10 kΩ	Carbon	1/2W	10	Morganite Type S
R28	1.5 kΩ	High stability	1/2W	5	Welwyn Metox F20
R29	1.5 Ω	Wirewound	1W	2	APT Type ESF/R
R30	0.5 Ω	Wirewound	1W	2	APT Type ESF/R
R31	0.25 Ω	Wirewound	1W	2	APT Type ESF/R
R32	0.15 Ω	Wirewound	1W	2	APT Type ESF/R
R33	0.10 Ω	Wirewound	1W	2	APT Type ESF/R
R34	1 kΩ	Carbon	1/2W	10	Morganite Type S
R35	100 Ω	Carbon	1/2W	10	Morganite Type S
R36	680 Ω	High stability	1/2W	5	Welwyn Metox F20
R37	15 kΩ	High stability	1/2W	5	Welwyn Metox F20
R38	22 kΩ	Carbon	1/2W	10	Morganite Type S
R39	470 kΩ	High stability	1/4W	2	Radio Resistor 2HS2
R40	10 kΩ	Carbon	1/2W	10	Morganite Type S
R41	1.5 kΩ	High stability	1/2W	5	Welwyn Metox F20
R42	150 Ω	Carbon	1/2W	10	Morganite Type S
R43	4.7 kΩ	Carbon	1/2W	10	Morganite Type S
R44	8.2 kΩ	Carbon	1/2W	10	Morganite Type S
R45	22 kΩ	Carbon	1/2W	10	Morganite Type S

Cct. Ref.	Value	Description	Rating	Tol. ± %	Maker and Type
R46	180 Ω	High stability	1/2W	5	Welwyn Metox F20
R47	330 Ω	High stability	1/2W	5	Welwyn Metox F20
R48	47 kΩ	High stability	1/2W	5	Welwyn Metox F20
R49	330 Ω	High stability	1/2W	5	Welwyn Metox F20
R50	0.5 Ω	Wirewound	1W	2	APT
R51	2 kΩ	Wirewound	1W	1	APT Type SFM
R52	2 kΩ	Wirewound	1W	1	APT Type SFM
R53	2 kΩ	Wirewound	1W	1	APT Type SFM
R54	2 kΩ	Wirewound	1W	1	APT Type SFM
R55	900 Ω	Wirewound	1W	5	APT Type SFM
R56	4.7 Ω	Wirewound	1W	5	APT Type SFM
R57	1 Ω	Wirewound	1W	5	APT Type SFM
R58	1 Ω	Wirewound	1W	5	APT Type SFM
R59	22 Ω	Carbon	1/2W	10	Morganite Type S
RESISTORS, VARIABLE					
RV1	5 kΩ	Wirewound	1/2W	10	AB Metals 82W
RV2	250 Ω	Wirewound	1/2W	10	AB Metals 82W
RV3	5 kΩ	Wirewound	1/2W	10	AB Metals 82W
RV4	2.5 kΩ	Wirewound	2W	10	Colvern CLR3001/9
RV5	250 Ω	Wirewound	1/2W	10	AB Metals 82W
CAPACITORS, FIXED					
C 1	500 µF	Electrolytic	25V	100/-20	Plessey CE 1246
C 2	500 µF	Electrolytic	25V	+100/-20	Plessey CE 1246
C 3	500 µF	Electrolytic	25V	+100/-20	Plessey CE 1246
C 4	0.47 µF	Plastic Film	160V	10	Wima Type M
C 5	50 µF	Electrolytic	25V	+100/-20	Plessey CE 1201
C 6	1 µF	Plastic Film	160V	10	Wima Type M
C 7	4700 pF	Ceramic	750V	10	SRC Hi-K K3000/58
C 8	0.1 µF	Plastic Film	160V	10	Wima Type M
C 9	0.1 µF	Plastic Film	160V	10	Wima Type M
C10	2 µF	Electrolytic	50V	+100/-20	TCC CE68D
C11	3000 µF	Electrolytic	70V	+100/-20	Plessey CE1531/9
C12	250 µF	Electrolytic	25V	+100/-20	TCC CE117C
C13	8 µF	Electrolytic	25V	+100/-20	TCC CE5H
C14	1 µF	Plastic Film	160V	10	Wima Type M
C15	0.01 µF	Plastic Film	400V	10	Wima Type M
C16	0.22 µF	Plastic Film	160V	10	Wima Type M
C17	2700 pF	Ceramic	500V	+50/-20	Radio Resistor HK
C18	1 µF	Plastic Film	160V	10	Wima Type M
C19	1 µF	Plastic Film	160V	10	Wima Type M
C20	400 µF	Electrolytic	50V	+100/-20	4 x Plessey CE1339/29 (100 µF each)
SEMI-CONDUCTOR DEVICES					
SCR1		Silicon controlled rectifier			Transitron TCR 1005
VT 1		Transistor, NPN Silicon			Transitron ST701
VT 2		Transistor, NPN Silicon			Transitron ST701
VT 3		Transistor, PNP Silicon			Mullard BCZ11
VT 4		Transistor, PNP Germanium			Mullard OC23
VT 5		Transistor, PNP Germanium			Mullard OC28

Cct. Ref.	Description	Maker and Type
VT 6	Transistor, NPN Silicon	Transistron ST701
VT 7	Transistor, PNP Silicon	Mullard BCZ11
VT 8	Transistor, PNP Silicon	Mullard BCZ11
VT 9	Transistor, PNP Silicon	Mullard BCZ11
VT10	Transistor, PNP Silicon	Mullard BCZ11
ZD 1	Zener diode, 5.6V	GEC SX56
ZD 2	Zener diode, 9.0V	AEI VR9-F
ZD 3	Zener diode, 9.0V	AEI VR9-F
ZD 4	Zener diode, 5.6V	GEC SX56
ZD 5	Zener diode, 9.0V	AEI VR9-F
MR 1	Rectifier, Selenium	Siemens Halske B125 C140
MR 2	Rectifier, Selenium	Siemens Halske B125 C140
MR 3	Diode, Silicon	Transitron SG949A
MR 4	Diode, Silicon	Transitron SG949A
MR 5	Rectifier, Silicon	AEI SL103-A
MR 6	Rectifier, Silicon	AEI SL103-A
MR 7	Rectifier, Silicon	AEI SL103-A
MR 8	Rectifier, Silicon	AEI SL103-A
MR 9	Diode, Germanium	Mullard OA81
MR10	Diode, Silicon	Transitron SG949A
MR11	Diode, Silicon	Transitron SG949A
MR12	Diode, Germanium	Mullard OA81
MR13	Diode, Silicon	Plessey D1003
MISCELLANEOUS		
SW1	2-pole on/off	MEM Gridsw.1613 (ivy)
SW2	2-pole 5-position rotary	APT Drg. B17590
SW3	1-pole 6-position rotary	APT Drg. B17819
SW4	Push-button Change-over	Bulgin MP18, White
SW5	2-pole 2-position rotary	APT Drg. B18557
M 1	4 inch Rectangular Meter	APT Drg. C18556/2
T 1	Mains transformer	APT Pt.No. TX2608G
T 2	Pulse transformer	APT Pt.No. TX2700A
F 1	Fuse, cartridge, 2.5A	Belling Lee L562/2.5A
F 2	Fuse, cartridge, 2.5A	Belling Lee L562/2.5A
IP1	6.5V 0.15A Sub-miniature LES	Stella No. 65-15
PL1	Plug, 3-pin	Belling Lee L1436/P

The company reserves the right to fit substitute components of equivalent specification and performance.



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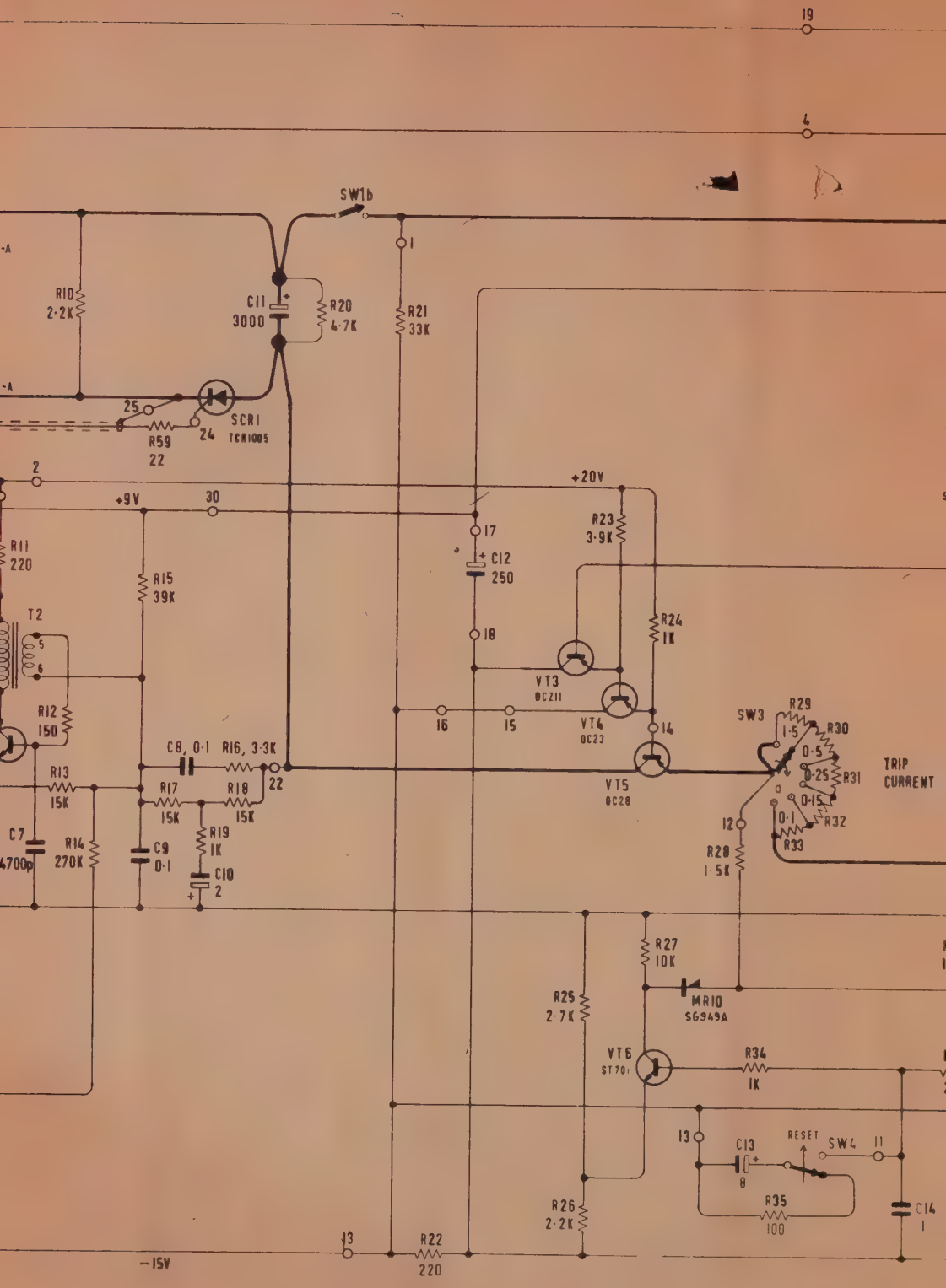
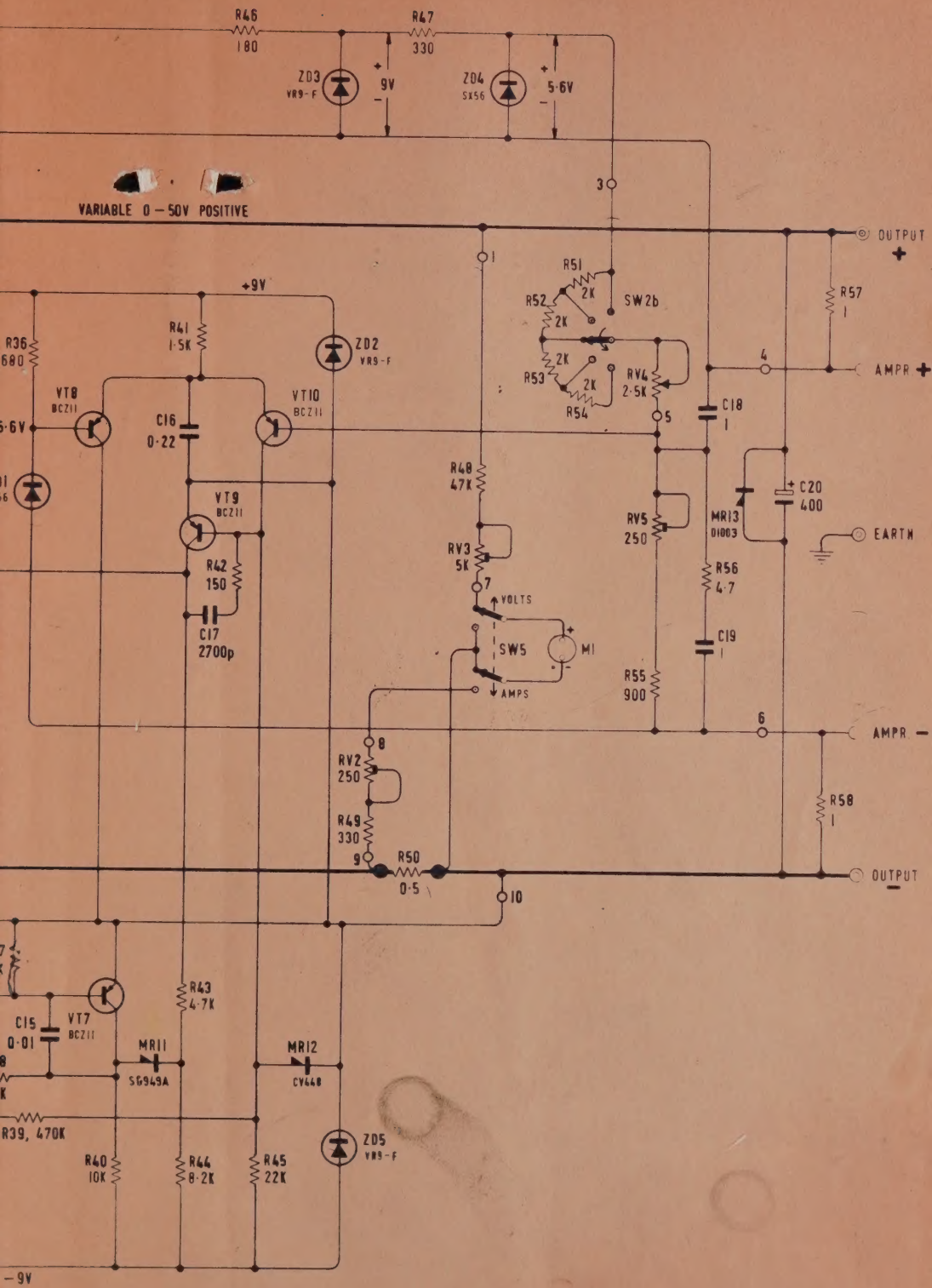

19
4
SW1b
1
R10
2·2K
C11
3000
R20
4·7K
R21
33K
25
24
SCR1
TCR1005
R59
22
2
+9V
30
+20V
R23
3·9K
17
C12
250
R11
220
R15
39K
T2
18
R24
1K
VT3
BCZ11
VT4
OC23
VT5
OC28
16
15
14
SW3
R29
1·5
R30
0·5
0·25
R31
0·15
R32
0·1
R33
TRIP
CURRENT
12
R28
1·5K
R12
150
C8, 0·1
R16, 3·3K
22
R13
15K
R17
15K
R18
15K
C7
4700p
R14
270K
C9
0·1
R19
1K
C10
2
R27
10K
MR10
SG949A
R25
2·7K
VT6
ST701
R34
1K
13
C13
8
RESET
SW4
11
R26
2·2K
R35
100
C14
1
13
R22
220
−15V



MODEL TCU 150
CIRCUIT DIAGRAM

FIG. 1

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